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NEW CONCEPTS IN STUDYING ELECTROSTATIC DISCHARGE HAZARDS OF PROPELLANTS, PYROTECHNICS AND EXPLOSIVES

by
C. James Dahn
Diane Jennings
Abdollah Kashani
&
Missy Nguyen

Safety Consulting Engineers, Inc.
Rosemont, Illinois 60018

ABSTRACT

A study of electrostatic discharge hazards was conducted to determine the worse case situation in handling and producing propellants, pyrotechnics and explosives (PEP). Electrostatic charge generation, storage and mechanisms of discharge were studied. External versus internal generated discharges were studied.

A set of guidelines were established to evaluate electrostatic charging, charge transfer, storage and discharges. Impedance matching is essential for ignition of a wide variety of materials in processing and handling.

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INTRODUCTION

As a result of numerous incidents attributed to electrostatic discharge initiations, there is a great need for having proven methods of testing sensitive materials. Military applications are of particular interest here because of the large-scale production, handling, and storage of explosive, propellant, and pyrotechnic items.

The purpose of this paper is threefold:

(1) to review the history of work on electrostatic sensitivity testing of explosive materials.

(2) to review the testing procedures performed by various government agencies and by Safety Consulting Engineers, Inc.

(3) to conduct electrostatic discharge tests using various methods in order to determine worst-case initiation thresholds.

ESD HAZARDS

Static electricity can be generated and retained in one of the following ways, thus creating an electrostatic ignition hazard:[1,2]

(1) Charging of explosive powders, large solid particles, or mixtures. This typically can occur from the pneumatic transport or loading of explosive materials in bulk form, sieving and grinding operations, and mixing/blending operations.

(2) Charging of surfaces that are made from poorly conducting substances which come in contact with explosive material. Typical scenarios for this include the use of Teflon or plastic coatings on rocket motor mandrels for the purpose of reducing metal-to-metal contact friction between parts and during mandrel extraction operations, and the use of large containers or piping made from or lined with materials possessing insulating properties.

(3) Charging of personnel in areas where explosive material operations are being carried out. Common instances of this can occur from walking on nonconducting flooring, wearing shoes with nonconducting soles, rising from a chair, brushing against an object, acquiring the charge from another object in the vicinity by the process of induction, and removing and article of clothing that contains synthetic fibers.

(4) Charging of metal objects that are isolated from ground and which come in contact with explosive material. This might be seen with process equipment that is involved in the direct handling of explosive materials or in the fabrication of explosive, propellant or pyrotechnic items.

ESD TESTING HISTORY

There has been much previous work regarding the development of useful electrostatic sensitivity testing procedures. Some highlights of this work is presented from a historical perspective in Table 1.[3]

ESD SENSITIVITY TESTING

The first step towards establishing safety measures is to have reliable methods for electrostatic discharge testing which relate to ESD mechanisms that might occur under processing and handling conditions. The immediate goals of such testing are (a) to determine how sensitive the material is in the presence of an electrostatic discharge; (b) to develop a mechanism that explains how a discharge takes place in the material under study; and (c) to establish an acceptable value for the minimum ignition energy for each potential condition.

Government Agency Testing Procedures

Several government agencies have contributed extensively to the field of electrostatic sensitivity testing of explosive materials; namely the U.S. Bureau of Mines, the Picatinny Arsenal, the Los Alamos National Laboratory, the Naval Weapons Center, and the Naval Ordnance Station. All of these agencies have developed an approaching-electrode device for which only the testing parameters vary. This information is summarized in Table 2.[4,5,7,8] The approaching-electrode devices developed by the U.S. Bureau of Mines and the Picatinny Arsenal are shown in Figures 1, 2, and 3. The electrode devices developed by the Los Alamos National Laboratory, the Naval Weapons Center, and the Naval Ordnance Station are similar in design. The approaching-electrode device is described below.[4,5,7,8]

The basic principle of operation for the approaching-electrode apparatus involves charging capacitors from a high voltage DC supply, and then discharging the stored energy through the test material under study. The electrical discharge occurs in the region between a needle or a flat plate, referred to as the upper electrode, and a steel cylinder base that holds the sample in place. The approaching-electrode (spring-loaded) apparatus is rapidly released from the sample being tested. The sensitivity of the material is evaluated as a discharged spark that jumps a critical distance across an air gap and through the sample. Steel phonograph needles or brass pins are utilized for the upper electrode. Test samples can be unconfined on a flat metal disk or confined by placing the powder in a plastic tube or by placing tape over the powder on a disk.

The position of the needle or flat plate is adjusted by a set screw so that the space between the base and the upper electrode is approximately equal to the critical gap for a given voltage. This distance is usually estimated by running trial tests. After sample preparation, the upper electrode is cocked to its initial position and the voltage supply is turned on. Charging of the capacitor is monitored by an electrostatic voltmeter. When it reaches the desired level, a switch is closed which allows electrical contact to be made between the capacitor and the upper electrode. When the electrode release button is pressed, the needle or flat plate undergoes a contracting motion and evidence of a reaction is noted by examining the test sample.

How results are obtained from the approaching-electrode test does depend upon which agency's procedure is being used. The U.S. Bureau of Mines and the Los Alamos National Laboratory fix the voltage, vary the size of the capacitor, and conduct several trials at each discharge energy level. The ignition probability point method is then applied to the data. The Picatinny Arsenal procedure calls for varying the voltage in an incremental fashion for a series of different sized capacitors. The Naval Weapons Center fixes the discharge energy (by fixing the voltage and capacitance) at a level that simulates a discharge from a person. Several consecutive tests showing a "no initiation" response are required before the material under study can be authorized for use in military applications. The Naval Ordnance Station follows this same test format, the exception being that a range of fixed energy levels are used.

General Testing Procedures at Safety Consulting Engineers, Inc.

Safety Consulting Engineers also routinely performs electrostatic sensitivity testing of explosive, propellant, and pyrotechnic materials. There are five basic electrode configurations used: ball, sharp, flat plate, pipette plate and pipette sharp. These configurations are shown in Figure 5 and a brief description of each is provided below.

1. Ball Electrode

The upper electrode is a ball electrode configuration consisting of a solid metal sphere approximately 0.925" in diameter attached to a copper rod. The base electrode is a flat metal disk that is attached by adhesive to an insulating surface. Two different sizes of disks are used, depending upon the size of the sample being tested: 0.3" and 2". The ball electrode is connected directly to the positive side of a charged capacitor circuit; when a vacuum relay switch is tripped, the capacitor discharges its energy through various resistances to the ball and subsequently through the sample. This test can be carried out as a no-gap, fixed-gap or approaching-electrode procedure. The no-gap procedure requires that the ball electrode just touch the sample. The fixed-gap procedure requires that the ball electrode be suspended a distance that is slightly above the sample. The approaching-electrode procedure involves lowering the charged ball to a point just slightly above the surface of the sample.

2. Sharp Electrode

The sharp electrode setup is similar in design and operation to the ball electrode; however, the upper electrode is instead a piece of copper wire 0.10" in diameter sharpened to a point at its lower end. The sharp electrode setup can be used in a fixed-gap or approaching-electrode test.

3. Flat Plate Electrode

The flat plate electrode test is operated in the same manner as the metal ball and the pointed-probe electrode tests. In this case; however, the upper electrode consists of a metal disk with raised edges, similar in shape to a bottle cap. The outside diameter of the disk is approximately 0.955" and the inside diameter, comprising the actual contact surface, is about 0.755". The flat plate electrode is used to determine the energy at which electrical breakdown causing ignition of the material occurs. Both breakdown and initiation thresholds can be found using this test. A burn hole that passes completely through the sample is evidence of electrical breakdown. The flat plate electrode setup can be used in a no-gap or fixed-gap test position.

4. Pipette Plate Electrode

The pipette plate electrode configuration receives its name from the manner in which the sample is confined during testing. Samples are first prepared for this test by obtaining 1/2" long pieces from a plastic pipette. A small amount of test powder is loosely scooped into a pipette holder until a sample height of about 0.1" is achieved. The electrode setup is that of a set of flat plates separated by a fixed distance and shielded by a plastic cover. The sample holder is positioned between two copper wire electrodes 0.10" in diameter by raising the upper electrode is then lowered into the tube until it just touches the powder sample without compressing it. After placing a plastic shield over the electrode region, the apparatus is ready for operation. As with the other electrode tests, a charged capacitor discharges energy via resistors to the upper plate and subsequently through the sample. A white spark indicates no reaction with the explosive material, while a colorless spark indicates that a partial reaction has occurred. If the sample holder is ruptured, ignition is said to have occurred.

5. Pipette Sharp Electrode

The pipette sharp electrode setup is similar to the pipette plate electrode, with the exception being that the upper electrode is a sharpened piece of 0.10" diameter copper wire. The pointed end of the electrode is allowed to just contact the sample, the energy in the capacitor is discharged, and evidence of a reaction is recorded in the same manner as with the pipette plate electrode test.

The electrode configuration is not the only important parameter in electrostatic sensitivity testing. The configuration of the electrical circuit affects the results as well. At safety Consulting Engineers, Inc. three different circuit arrangements have been used in testing explosive materials: a capacitive circuit, a capacitive-resistive circuit, and a capacitive-inductive circuit. These circuit arrangements are shown in Figure 6.

TEST PERFORMED AT SAFETY CONSULTING ENGINEERS, INC.

Test Description

Electrostatic sensitivity tests on black powder, nitrocellulose, and solid rocket propellant have been performed at Safety Consulting Engineers. A wide variety of electrode and circuit combinations were tried, so that minimum ignition energies could be calculated and compared for each material. The black powder was FFF grade. The nitrocellulose was tested in a powder form having 13.4% nitrogen composition, and in sheets having a 70% nitrocellulose content and a thickness of 0.04". The solid rocket propellant consists (by weight) of 68% ammonium perchlorate, 20% powdered aluminum, and 12% HTPB-based binder. The propellant was tested in minus 20 mesh powder form and sheets having a thickness of 0.04". Black powder and nitrocellulose were the reference materials for these tests. The specific information being sought from these tests is the effects that the electrode configuration, the circuit configuration, and the circuit resistance have on causing electrostatic initiation.

To determine the electrode configuration effect, electrodes were tested with a capacitive-resistive tester, in which the capacitor discharged its energy through either zero, 100 kilohms, or noe megohm resistance.

To determine the circuit configuration and circuit resistance effects, electrodes were tested with a capacitive-resistive and a capacitative-inductive test apparatus. The resistances used within these circuits were also zero 100 kilohms, and 1 megohm. Thus, a variety of circuit configurations were obtained in the SCE-designed instruments. These include capacitative-only, capacitative-resistive, capacitative-inductive, and capacitative-resistive-inductive.

Test Results

Some selective results from these tests are presented in Tables 3, 4, and 5.

What can be drawn from Table 3 is a ranking of the electrode configurations in terms of the level of stored energy that caused ignition. The materials tested showed different levels of sensitivity depending upon the electrode that was used for the test. In general, the ball electrode yields the lowest energy for ignition, so that explosives look very sensitive when using this apparatus. the sharp electrode ranks next, showing somewhat less sensitivity. This is followed by the flat plate electrode, which makes the explosive appear not very sensitive to ignition. The pipette plate electrode falls somewhere in between the other electrodes, having given much less definite results that vary widely with the type of explosive powder being tested.

It can be concluded from Table 4 that, given the same electrode, using the capacitative-inductive test apparatus generally yields lower stored energy values. This implies that if an explosive material is tested with this apparatus, it will look more sensitive to ignition than if it is tested with the capacitative-resistive apparatus. Thus, the presence of an impedance in the test circuit has a definite effect on the electrostatic test sensitivity of explosive materials.

Additional information can be drawn from Table 4 since two different electrodes were studied. The ball electrode generally gives lower energy values than the sharp electrode when using the capacitative-resistive tester. The exact opposite occurs with the capacitative-inductive tester, in that the sharp electrode gives lower energy values than the ball electrode. Thus, in one situation, the explosive material looks more sensitive with the ball electrode, and under different conditions, it looks more sensitive with the sharp electrode.

The energies listed in Tables 3 and 4 are the minimum stored values in the capacitors that were capable of causing a discharge. The spark energies comparison of the spark energy with the stored energy for tests using the sharp, flat plate, and ball electrodes is provided in Table 5. The spark energy is the true measure of a material's sensitivity, and in all cases shown in Table 5, it proved to be less than the stored energy, regardless of the capacitance and the voltage used in the test.

Conclusion

The overall conclusion that can be drawn from the tests performed at Safety Consulting Engineers is that the combined effect of electrode configuration and circuit configuration makes explosive materials respond differently under varying test conditions. Thus, it remains a difficult task to specify a minimum initiation threshold value that could be used reliably in any situation for a given explosive.

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TABLE 1

HISTORICAL PERSPECTIVE OF WORK ON
ESD SENSITIVITY TESTING OF EXPLOSIVE MATERIALS

Year	Researcher	Nature of Work
1947	Fleischer and Burtle	Described effect of electrostatic charges on variety of lead azides
1949	Rathburg and Schmitz	Measured electrostatic and ignition sensitivity of primary and initiating explosives
1953	Peace	Noted presence of electrostatic charges on sieved explosive powders
1954	Damon and vanDolah	Reported electrostatic spark test results for several explosive samples
1956	Moore, Sumner and Wyatt	Developed electrostatic spark sensitivity tests for initiators
1959	Sciafe and Wyatt	Continued work on spark sensitivity tests for initiators
1963	Jackson	Studied electrical characteristics of secondary explosives
1965	Clear	Outlined test procedures for electrostatic sensitivity of explosives
1967	Hannah and Polson	Observed accumulation of static charge during handling of lead azide
1969	Montesi	Described a fixed-gap ESD apparatus for testing explosives
1969	Perkins	Review of current ESD testing methods for explosives
1972	Westgate, Pollock and Kirshenbaum	Reviewed current ESD testing practices used on explosives at some major government agencies

TABLE 2

SUMMARY OF ESD TESTING PARAMETERS

	Apparatus & Type of Electrode	Sample Quanity	Sample Confined	Gap Distance	Capacitance	Applied Voltage	Energy Stored In Capacitor
U.S. Bureau of Mines	Approaching Point	50 mg	Partly and No	---	0.0001 - 1.0 F	5 KV Fixed	0.0013 - 12.50 J
Picatinny Arsenal	Approaching Point	5-10 mg	Yes	0.18 mm	54 - 6980 pF	7.5 KV and down	Not specified
Picatinny Arsenal	Approaching Point	3-8 mg	Partly	0.19 mm	54 - 6980 pF	7.5 KV and down	Not specified
Los Alamos National Laboratory	Approaching Point	Constant-volume basis	Yes	Not Known	0.0002 - 3.0 F	5 KV Fixed	Range not specified
Naval Weapons Center	Approaching Point	50 mg	No	Not Known	0.0001 - 0.5 F	5 KV Fixed	0.25 J
Naval Ordnance Station	Approaching Point	50 mg	No	Not Known	0.0001 - 0.1 F	5 KV Fixed	0.001 - 6.25 J
Safety Consulting Engineers, Inc.	Pipette Plate	50 mg	Yes	2.5 mm	0.0005 - 0.1 F	up to 25 KV	0.001 - 24 J
Safety Consulting Engineers, Inc.	Fixed and Approaching Ball	50 mg - 10 g	No	Variable	0.0005 - 0.1 F	up to 25 KV	0.001 - 24 J

TABLE 3

EFFECT OR ELECTRODE CONFIGURATION

ON STORED ENERGY REQUIRED

TO ESD INITIATE MATERIALS

Capacitive - Resistive ESD Testing 1 M Resistance

(ENERGY IN mJ)

ELECTRODE	PROPELLANT SHEET	PROPELLANT POWDER	NC SHEET	NC (13.4%) POWDER	BLACK POWDER
Ball	3200	320	-	36	49
Ball-Approaching	3200	>2800	405	144	640
Flat Plate	5500	720	6050	-	36
Sharp	3610	550	4500	49	122
Sharp-Approaching	8450	-	-	-	-
Pipette Plate	-	500	-	64	289

TABLE 4

EFFECT OF CIRCUIT RESISTANCE & TEST APPARATUS

ON STORED ESD ENERGY THRESHOLDS

CAPACITIVE-RESISTIVE TESTER	RESISTANCE OHM	STORED ESD ENERGY - mJ PROPELLANT POWDER	13.4% NC	BLACK POWDER
Ball Electrode	0	156		360
	100 K	300	90.2	640
	1 M	320	90.2	49
Sharp Electrode	0	-	-	-
	100 K	-	49	810
	1 M	550	49	122
INDUCTIVE CAPACITIVE TESTER				
Ball Electrode	0	156	36	100
	100 K	300	30	169
	1 M	>12,800	36	36
Pointed Electrode	0	-	42	81
	100 K	-	36	64
	1 M	-	42	49

TABLE 5

SPARK ENERGY AS A FUNCTION

OF STORED

CAPACITOR ENERGY

CAPACITOR		CAPACITOR STORED ENERGY		SPARK ENERGY
CAPACITANCE	VOLTAGE	(mJ)	ELECTRODE	(mJ)
0.1	12,000	7200	Sharp	325.0
0.01	17,000	1445	Sharp	72.0 to 270.0
0.002	7,000	49	Sharp	24.0
0.002	7,000	49	Flat Plate	14.7
0.002	7,000	49	Ball	14.7

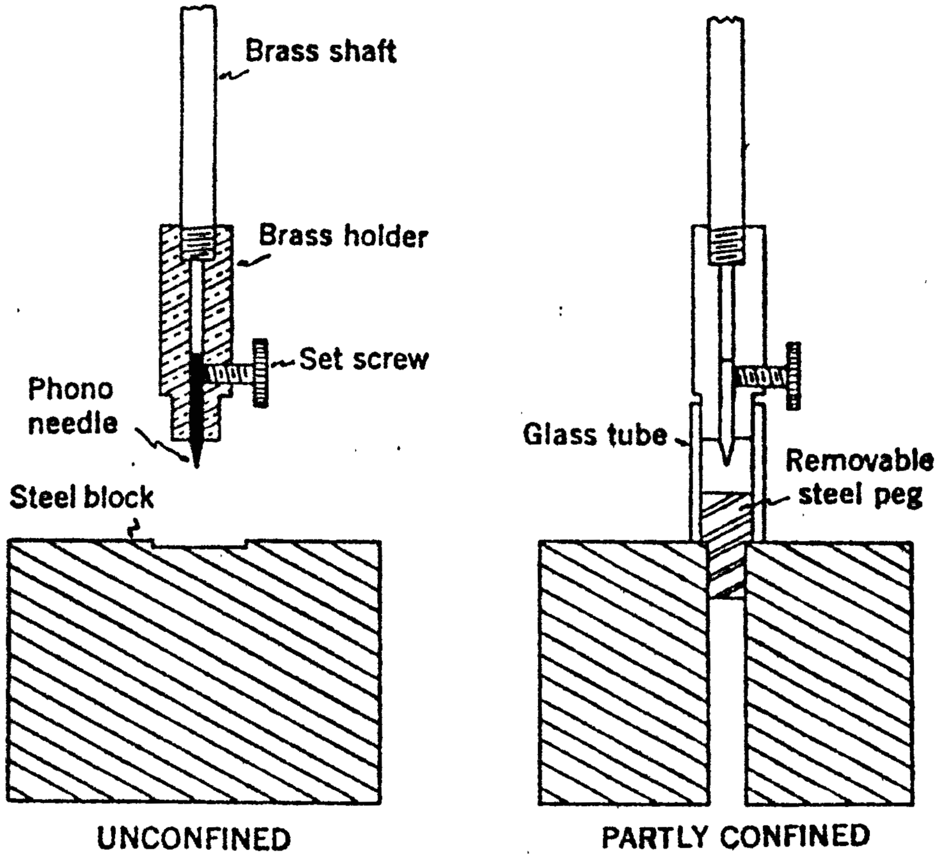


Figure 1. U.S. Bureau of Mines Approaching-Needle Electrode Apparatus. (Ref 4)

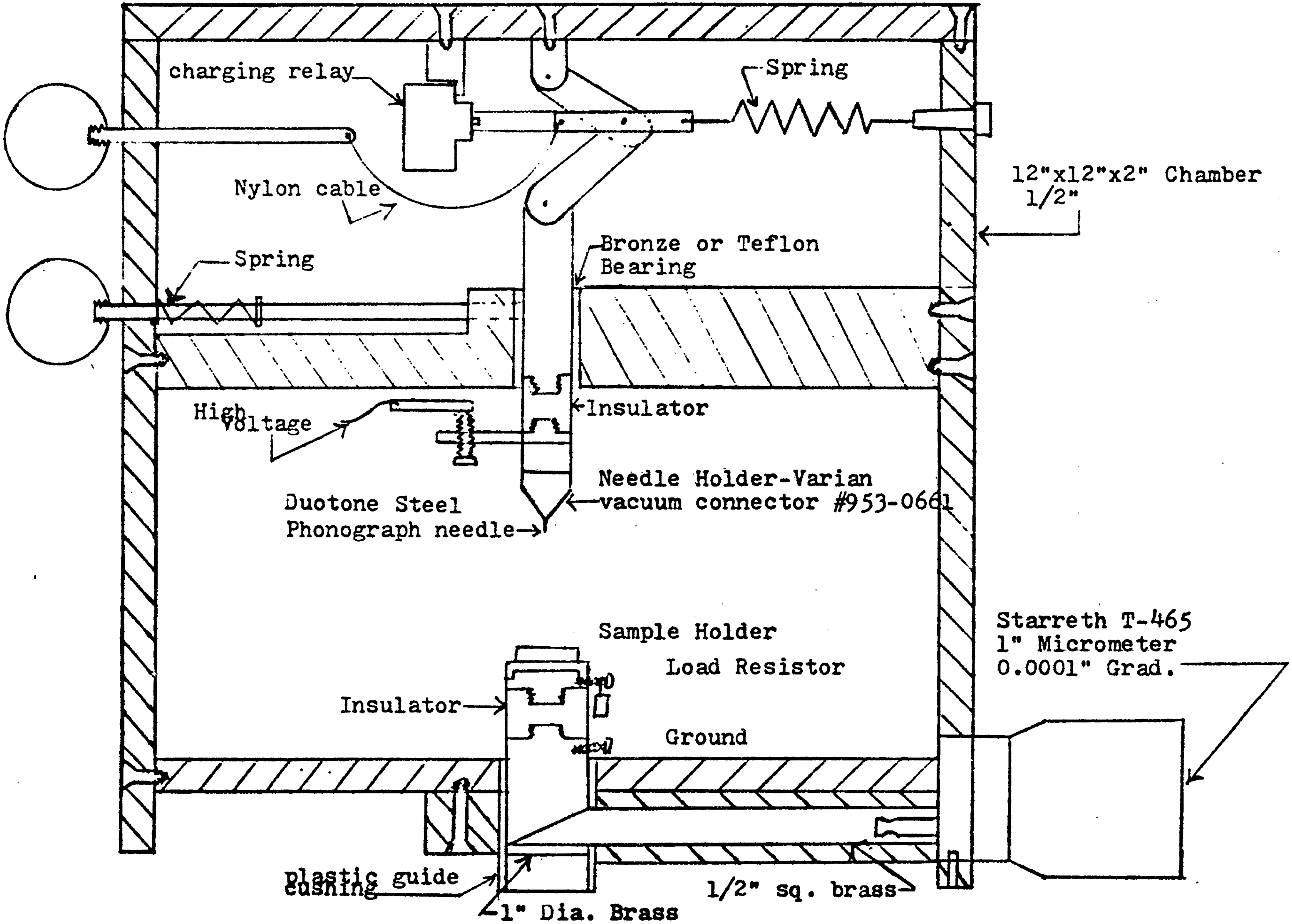


Figure 2. Picatinny Arsenal Approaching-Needle Electrode Apparatus. (Ref 6)

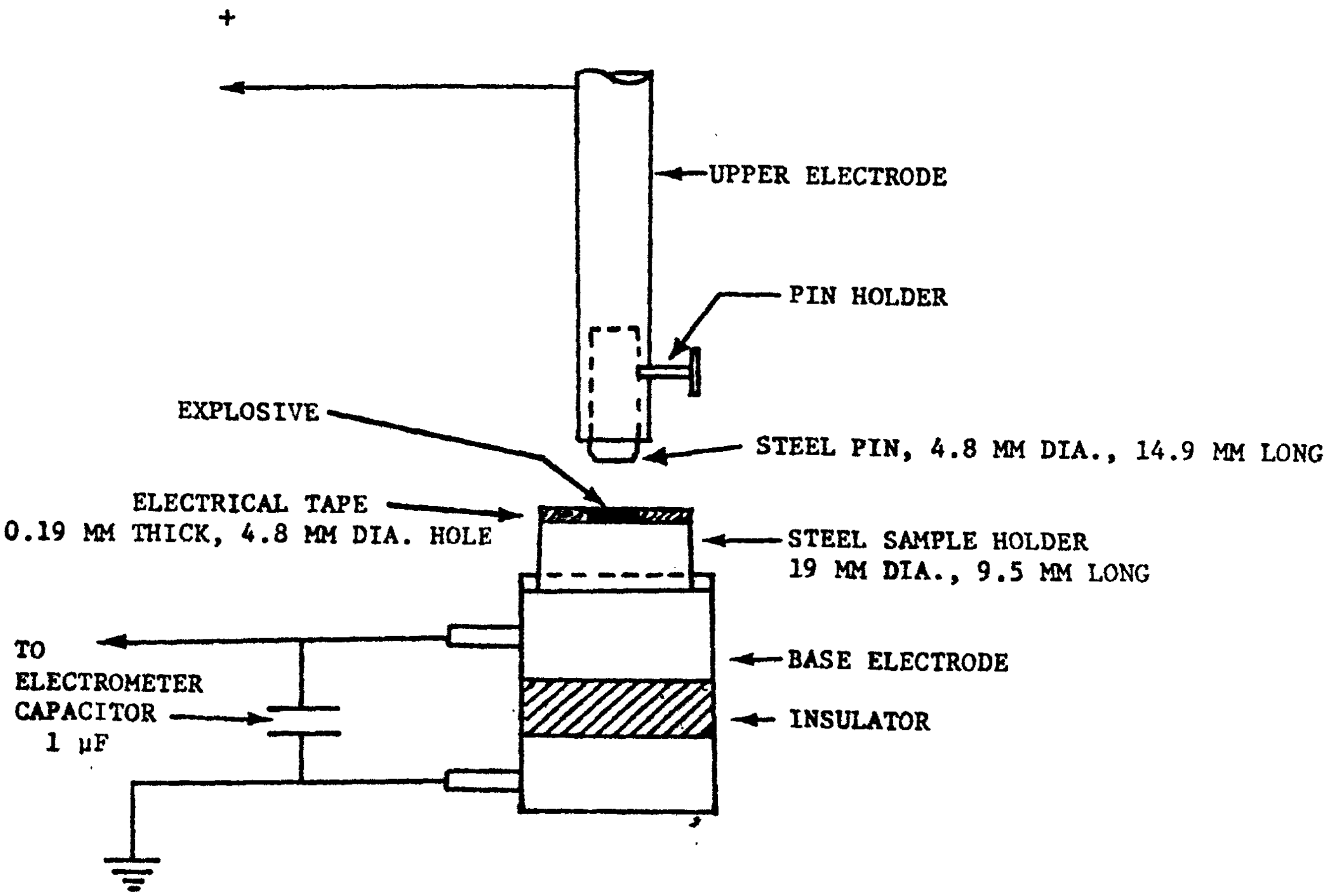
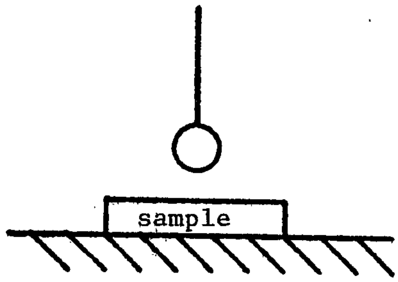
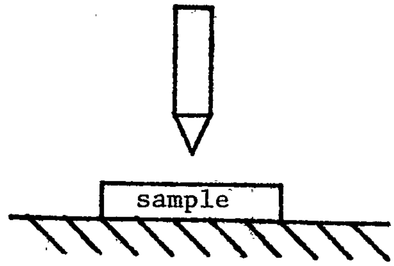


Figure 3. Picatinny Arsenal Approaching-Plate Electrode Apparatus. (Ref 5)



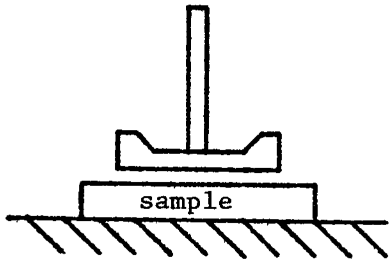
(A) Ball Electrode

No-gap, fixed-gap, and approaching test positions



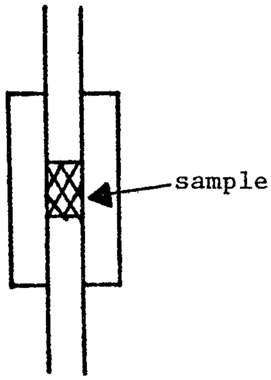
(B) Sharp Electrode

Fixed-gap and approaching test positions



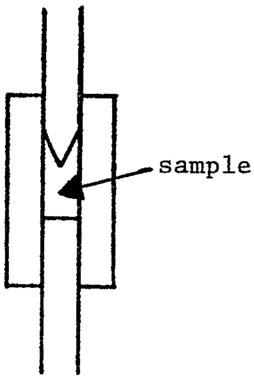
(C) Flat Plate Electrode

No-gap and fixed-gap test positions



(D) Pipette Plate Electrode

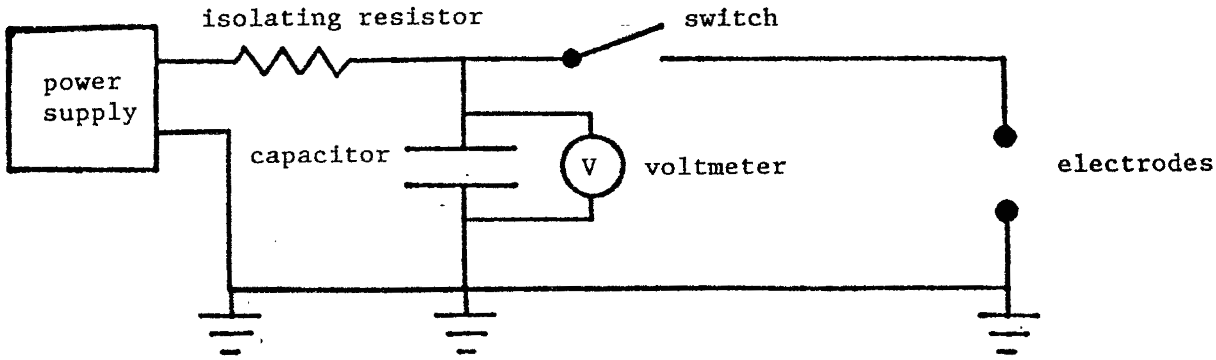
Fixed test position



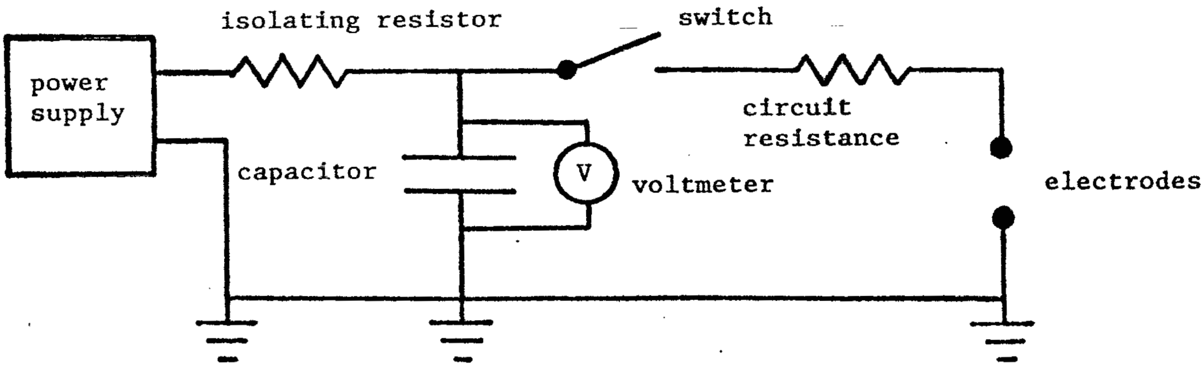
(E) Pipette Sharp Electrode

Fixed test position

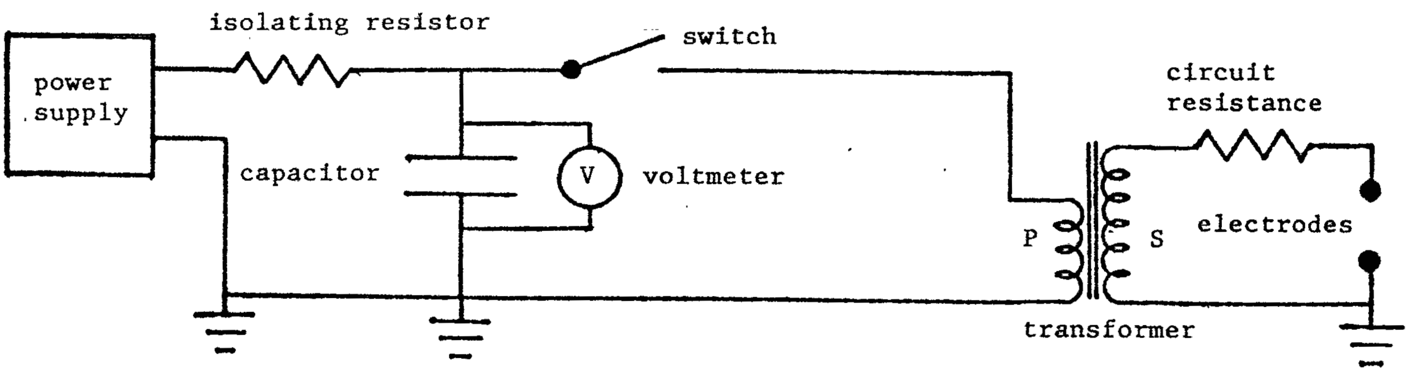
Figure 4. Electrode Configurations Used in Electrostatic Sensitivity Testers at Safety Consulting Engineers.



(A) Capacitive Circuit



(B) Capacitive-Resistive Circuit



(C) Capacitive-Inductive Circuit

Figure 5. Electrical Circuit Configurations for Electrostatic Sensitivity Testers at Safety Consulting Engineers.